Halley (E.) G. 531

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Mr. Edmund Halley's explicat: of ye Tydes

May it Pleaſe THE KING'S MOST EXCELLENT MAJESTY.

~~537 g 30~~

I Could not have preſumed to approach your Majeſties Royall Preſence with a Book of this Nature, had I not been aſſured that, when the weighty Affairs of your Government permit it, your Majeſty has frequently ſhewn your ſelf enclined to favour *Mechanical* and *Philoſophical* Diſcoveries: And I may be bold to ſay, that if ever Book was worthy the favourable acceptance of a Prince, this wherein ſo many and ſo great Diſcoveries concerning the conſtitution of the Viſible World are made out, and put paſt diſpute, muſt needs be grateful to your Majeſty; eſpecially being the Labours of a worthy Subject of your own, and a Member of that *Royall Society* founded by your late Royall Brother, for the advancement of Natural Knowledge, and which now Flouriſhes under your Majeſties moſt Gracious Protection.

537. g. 30.

But being ſenſible of the little Leiſure which Care of the Publick leaves to Princes, I believed it neceſſary to preſent with the Book a ſhort Extract of the Matters conteined, together with a *Specimen* thereof, in the genuine Solution of the Cauſe of the *Tides* in the Ocean; a thing frequently attempted, but till now without ſucceſs: Whereby your Majeſty may judge of the reſt of the performances of the Author.

The ſole Principle upon which this Author proceeds to explain moſt of the great and ſurpriſing appearances of Nature, is no other than that of *Gravity*, whereby in the Earth all Bodies have a tendency towards its Center; as is moſt evident: and from undoubted Arguments its proved, that there is ſuch a Gravitation towards the Centers of the Sun, Moon and all the Planets.

From this principle, as a neceſſary conſequence, follows the Spharical Figure of the Earth and Sea, and of all the other Cæleſtial Bodies: and tho' the tenacity and firmneſs of the Solid Parts ſupport the inequalities of the Land above the level; yet the Fluids, preſſing equally and eaſily yeilding to each other, ſoon reſtore the *Æquilibrium*, if diſturbed, and maintain the exact Figure of the Globe.

Now this force of Deſcent of Bodies towards the Center is not in all places alike, but is ſtill leſs and leſs, as the diſtance from the Center encreaſes: and in this Book it is demonſtrated, that this force decreaſes as the Square of the diſtance increaſes; that is, the weight of Bodies and the force of their Fall is leſs, in parts more removed from the Center, in the proportion of the ſquares of the diſtance. So as for Example, a Tun weight on the ſurface of the Earth, if it were raiſed to the height of 4000 miles, which I ſuppoſe the ſemidiameter of the Earth, would weigh but $\frac{1}{4}$ of a Tun or 5 hundred weight: if to 12000 miles or 3 ſemidiameters from the ſurface, that is 4 from the center, it would weigh but $\frac{1}{16}$ part of the weight on the ſurface, or a hundred and quarter: So that it would be as eaſy for the ſtrength of

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a man, at that height, to carry a Tun weight, as here to carry a hundred and quarter. And in the ſame proportion does the Velocities of the fall of Bodies decreaſe: for whereas on the ſurface of the Earth all things fall 16 foot in a ſecond, at one ſemidiameter above this fall is but 4 foot; and at 3 ſemidiameters, or 4 from the center it is but $\frac{1}{16}$ of the fall at the ſurface, or but one foot in a ſecond: and at greater diſtances both weight and fall become very ſmall, but yet at all given diſtances is ſtill ſome thing, tho' the effect become inſenſible. At the diſtance of the Moon (which I will ſuppoſe 60 ſemidiameters of the Earth) 3600 pounds weigh but one pound, and the fall of Bodies is but $\frac{16}{3600}$ of a foot in a ſecond, or 16 foot in a minute; that is, a body ſo far off deſcends in a minute no more than the ſame at the ſurface of the Earth would do in a ſecond of Time.

As was ſaid before, the ſame force decreaſing after the ſame manner is evidently found in the Sun, Moon and all the Planets; but more eſpecially in the Sun, whoſe force is prodigious; becoming ſenſible even in the immenſe diſtance of *Saturn*: This gives room to ſuſpect that the force of Gravity is in the Celeſtial Globes proportional to the quantity of Matter in each of them: and the Sun being at leaſt ten thouſand times as bigg as the Earth, its Gravitation or attracting Force, is found to be at leaſt ten thouſand times as much as that of the Earth, acting on Bodies at the ſame diſtances.

This law of the decreaſe of Gravity being demonſtratively proved, and put paſt contradiction; the Author with great Sagacity inquires into the neceſſary conſequences of this Suppoſition; whereby he finds the genuine cauſe of the ſeveral appearences in the Theory of the Moon and Planets, and diſcovers the hitherto unknown laws of the Motion of Comets and of the Ebbing and Flowing of the Sea. Each of which are ſubjects that have heretofore taken up much larger Volumes, but truth being uniforme and alwaies the ſame, it is admirable to obſerve how eaſily and how ſatisfactorily Solutions are given in very abſtruſe and difficult matters, when once true and genuine Principles are obtained: And on the other hand it may be wondred that, notwithſtanding the great facility of truth, and the perplexity and nonconſequences that alwaies attend erronious ſuppoſitions, theſe great diſcoveries ſhould have eſcaped the Acute diſquiſitions of the beſt Philoſophical Heads of all paſt ages, and be reſerved to be recorded to Poſterity, among the Glorious Acquiſitions your Nations juſtly promiſe themſelves, during the courſe of your Majeſties happy Reign over us:

The Theory of the Motion of the primary *Planets* is here ſhewn to be nothing elſe, but the contemplation of the Curve Lines which Bodies caſt with a given velocity, in a given direction, and at the ſame time drawn towards the Sun by its gravitating Power, would deſcribe. Or, which is all one, that the Orbs of the Planets are ſuch Curve Lines as a ſhot from a Gun deſcribes in the Air, being caſt according to the direction of the Piece, but bent into a crooked Line by the ſupervening tendency towards the Earths Center: And the Planets being ſuppoſed to be projected with a given force, and attracted towards the Sun, after the aforeſaid manner, are here proved to deſcribe ſuch Figures as anſwer punctually to all that the Induſtry of this and the laſt Age has obſerved in the Planetary Motions. So that it appears that there is no need of ſolid Orbs and Intelligences, as the Ancients imagined, nor yet of *Vortices* or Whirlpools of the Celeſtial Matter, as *Des Cartes* ſuppoſes; but the whole affair is ſimply and Mechanicall performed, upon the ſole ſuppoſition of a gravitation towards the Sun; which cannot be denied.

The Motion of *Comets* is here ſhewn to be compounded of the ſame Elements, and not to differ from Planets, but in their greater ſwiftneſs, whereby overpowering the gravity that ſhould hold them to the Sun, as it does the Planets, they flie off againe, and diſtance themſelves from the Sun and Earth, ſo that they ſoon are

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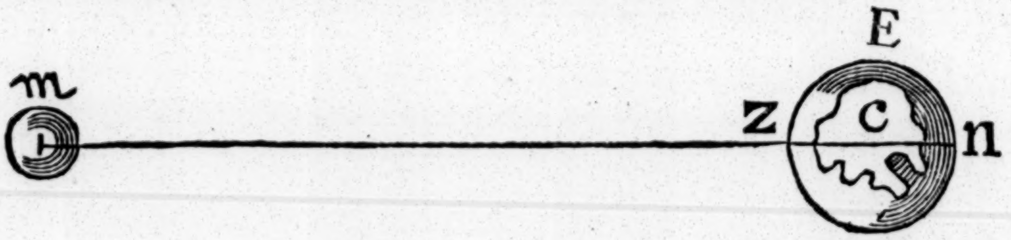
out of ſight: and the fewneſs and inaccuracy of the obſervations Antiquity has left us, are not ſufficient to determine whether the ſame Comet ever return again. But this Author has ſhewn how Geometrically to determine the Orb of a Comet from obſervations, and to finde his diſtance from the Earth and Sun, which was never before done.

The third thing here done is the Theory of the Moon, all the Inequalities of whoſe motion are proved to ariſe from the ſame principles, only here the effect of two centers operating on or attracting a projected body comes to be conſidered; for the Moon tho' principally attracted by the Earth and moving round it, does together with the Earth move round the Sun once in a Year, and is according as ſhe is nearer or farther from the Sun, drawn by him more or leſs than the Center of the Earth, about which ſhe moves; whence ariſe ſeveral irregularities in her motion, of all which the Author in this Book, with no leſs ſubtilty than Induſtry, has given a full account. And tho' by reaſon of the great complication of the problem, he has not yet been able to make it purely Geometrical, tis to be hoped, that in ſome farther Eſſay he may ſurmount the difficulty, and having perfected the Theory of the Moon, the long deſired diſcovery of the Longitude (which at Sea is only practicable this way) may at length be brought to light, to the great honour of your Majeſty and advantage of your Subjects.

All the ſurprizing Phenomena of the Flux and Reflux of the Sea are in like manner ſhewn to proceed from the ſame principle; which I deſign more largely to inſiſt on, ſince the matter of fact is in this caſe much better known to your Majeſty than in the foregoing.

If the Earth were alone,that is to ſay, not affected by the actions of the Sun and Moon, it is not to be doubted but the Ocean being equally preſſed by the force of Gravity towards the center, would continue in a perfect ſtagnation, always at the ſame hight, without ebbing or flowing; But it being not to be denied that the Sun and Moon have a like principle of Gravitation towards their Centers, and that the Earth is within the activity of their attractions, it will plainly follow that the equality of the preſſure of Gravity towards the Center will thereby be diſturbed; and tho' the ſmallneſs of theſe forces, in reſpect of the Gravitation towards the Earths Center, renders them altogether imperceptible by any experiments we can deviſe, yet the Ocean being fluid and yeilding to the leaſt force, by its riſing ſhews where it is leſs preſt, and where it is more preſt by its ſinking.

Now if we ſuppoſe the force of the Moons attraction to decreaſe as the ſquare of the diſtance from its Center increaſes (as in the Earth and other Celeſtial Bodies) we ſhall find, that where the Moon is perpendicularly either above or below the Horizon, either in Zenith or Nadir, there the force of Gravity is moſt of all diminiſhed, and conſequently that there the Ocean muſt neceſſarily ſwell by the coming in of the water from thoſe parts where the preſſure is greateſt, *viz.* in thoſe places where the Moon is near the Horizon: But that this may be the better underſtood, I thought it needful to add the following Figure, where *M* is the Moon, *E* the Earth, *C* its Center, and Z the place where the Moon is in the Zenith, *N* where in the Nadir.



Now by the Hypotheſis, it is evident that the Water in *Z* being nearer, is more drawn by the Moon than the Center of the Earth *C*, and that again more than the water in *N*, wherefore the water in Z has a tendency towards the Moon, contrary to that of Gravity, being equal to the exceſs of the Gravitation in *Z* above that in *C*: And in the other caſe, the water in *N*, tending

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leſs towards the Moon that the Center *C*, is left behind, by as much as is the difference of the Gravitations towards the Moon in *C* and *N*. This rightly underſtood, it follows plainly that the Sea, which otherwiſe would be Spherical, upon the preſſure of the Moon, muſt form it ſelf into a Spheroidal or Oval figure, whoſe longeſt diameter is where the Moon is Vertical, and ſhorteſt where ſhe is in the Horizon; and that the Moon ſhifting her poſition as ſhe turns round the Earth once a-day, this Oval of water ſhifts with her, occaſioning thereby the two floods and ebbs obſervable in each 25 hours.

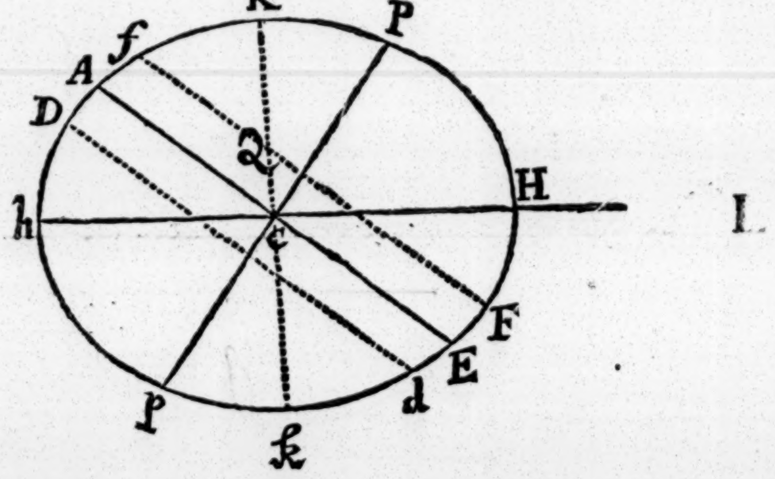
And this may ſuffice as to the general cauſe of the Tides; it remains now to ſhew how naturally this notion accounts for all the particulars that has been obſerved about them; ſo that there can be no room left to doubt but that this is the true cauſe thereof.

The Spring Tides upon the new and full Moons, and Neap Tides on the Quarters are occaſioned by the attractive force of the Sun in the new and full conſpiring with the attraction of the Moon and producing a Tide by their united forces: whereas in the Quarters the Sun raiſes the water where the Moon depreſſes it, and the contrary; ſo as the Tides are made only by the difference of their attractions. That the force of the Sun is no greater in this caſe, proceeds from the very ſmall proportion the ſemidiameter of the Earth bares to the vaſt diſtance of the Sun.

It is alſo obſerved that *cæteris paribus* the Æquinoctial Spring Tides in *March* and *September*, or near them, are the Higheſt, and the Neap tides the Loweſt; which proceeds from the greater agitation of the *Waters*, when the fluid *Sphæroid* revolves about a great Circle of the Earth, than when it turns about in a leſſer Circle; it being plain that if the Moon were conſtituted in the Pole and there ſtood, that the Spheroid would have a fixt poſition, and that it would be always high Water under the Poles, and low Water every where under the Æquinoctial: and therefore the nearer the Moon approaches the Poles, the leſs is the agitation of the Ocean: which is always greateſt where the Moon is in the Æquinoctial, or fartheſt diſtant from the Poles. Whence the Sun and Moon, being either conjoyned or Oppoſite in the Æquinoctial, produce the greateſt Spring Tides; and the ſubſequent Neap Tides, being produced by the Tropical Moon in the Quarters, are always the leaſt Tides; whereas in *June* and *December* the Spring Tides are made by the Tropical Sun and Moon, and therefore leſs vigorous; and the Neap Tides by the Æquinoctial Moon, which therefore are the ſtronger; hence it happens that the difference between the Spring and Neap Tides, in theſe Months, is much leſs conſiderable than in *March* and *September*. And the reaſon why the very Higheſt Spring Tides are found to be rather before the Vernal and after the Autumnal Equinox, *viz.* in *February* and *October*, than preciſely upon them, is becauſe the Sun is nearer the Earth in the Winter Months, and ſo comes to have a greater effect in producing the Tides.

Hitherto we have conſidered ſuch affections of the Tides as are Univerſal, without relation to particular caſes; what follows from the differing Latitudes of places, will be eaſily underſtood by the following figure.

Let *A p E P* be the Earth covered over with very deep waters, *C* its Center, *P*, *p*, its Poles, *A E* the Æquinoctial, *F f* the parallel of Latitude of a place, *D d* another Parallel at equal diſtance



on the other ſide of the Equinoctial; *H*, *h* the two points where by the attraction of the Moon it is higheſt water; *K*, *k* two places

90 degree from the former, where it is low Water. The Spheroid deſcribed upon the diameters Hh, and kK, ſhall nearly repreſent the figure of the Sea, and Cf, CD, CF, Cd ſhall be the hights of the Sea in the places f, D, F, d, in all which it is High Water: and ſeeing that in twelve hours time, by the diurnall rotation of the Earth, the point F is tranſferred to f, and d to D: the hight of the Sea CF will be that of the high water when the Moon is preſent, and Cf that of the other high water, when the Moon is under the Earth: which in the caſe of this figure is leſs than the former CF. And in the oppoſite parallel Dd the contrary happens. The Riſing of the Water being alwais alternately greater and leſs in each place, when it is produced by the Moon declining ſenſibly from the Equinoctial; that being the greateſt of the two Highwaters, in each diurnall revolution of the Moon, wherein ſhe approaches neareſt either to the Zenith or Nadir of the place: whence it is that the Moon in Northern Signs, in this part of the World, makes the greateſt Tides when above the Earth, and in Southern Signs, when under the Earth: the Effect being always greateſt where the Moon is fartheſt from the Horizon, either above or below it. And this alternate increaſe and decreaſe of the Tides has been obſerved to hold true on the Coaſt of *England*, at *Briſtol* by Capt. *Sturmy*, and at *Plymouth* by Mr. *Colepreſſe*.

But the motions hitherto mentioned are ſomewhat altered by the libration of the water, whereby tho' the Action of the *Luminaries* ſhould ceaſe, the Flux and Reflux of the *Sea* would for ſome time continue: This conſervation of the impreſſed motion diminiſhes the differences that otherwiſe would be between two conſequent Tides, and is the reaſon why the higheſt Spring-Tides are not perciſely on the new and full Moons, nor the Neapes on the Quarters; but generally they are the third Tides after them, and ſometimes later.

All theſe things would regularly come to paſs, if the whole Earth were covered with Sea very deep; but by reaſon of the ſholeneſs of ſome places, and the narrowneſs of the Streights by which the Tides are in many caſes propagated; there ariſes a great diverſity in the effect, and not to be accounted for without an exact knowledg of all the circumſtances of the places, as of the poſition of the Land, and the breadth and depth of the Channels by which the Tide flows; for a very ſlow and imperceptible motion of the whole body of the water, where it is (for example) 2 miles deep, will ſuffice to raiſe its ſurface 10 or 12 feet in a Tides time; whereas if the ſame quantity of water were to be conveied upon a channel of 40 fathoms deep, it would require a very great ſtream to effect it, in ſo large Inlets as are the *Channel* of *England* and the *German Ocean*; whence the Tide is found to ſet ſtrongeſt in thoſe places where the Sea grows narroweſt; the ſame quantity of water being to pals through a ſmaller paſſage: this is moſt evident in the *Streights* between *Portland* and *Cape de Hague* in *Normandy*, where the Tide runs like a ſluice; and it would be yet more between *Dover* and *Calais*, if the Tide coming about the *Iſland* from the *North* did not check it. And this force being once impreſſed upon the water, continues to carry it about the level of the ordinary hight in the Ocean, particularly where the water meets a direct obſtacle, as it is at St. *Malo's*; and where it enters into a long channell, which running far into the land, grows very ſtreight at its extremity; as it is in the *Severn-Sea* at *Chepſtow* and *Briſtol*.

This ſholeneſs of the Sea and the intercurrent Continents are the reaſon that in the open Ocean the time of high water is not at the Moons appulſe to the Meridian, but always ſome hours after it; as it is obſerved upon all the Weſt Coaſt of *Europe* and *Africa*, from *Ireland* to the *Cape* of *Good-Hope*: in all which a S. W. Moon makes high Water; and the ſame is reported to be on the Weſt ſide of *America*. But it would be endleſs to accont

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for all thoſe particularities, which are conſequences of this *Hypotheſis*; as why *Lakes*, ſuch as the *Caſpian Sea*; and *Mediterranian-Seas* ſuch as the *Black-Sea*, the *Streights* and *Baltick*, have no ſenſible Tides: For *Lakes* having no communication with the Ocean, can neither encreaſe nor diminiſh their Water, whereby to riſe and fall; and Seas that communicate by ſuch narrow Inletts and are of ſo immenſe an extent, cannot in a few hours time receive or empty Water enough to raiſe or ſink their Surface any thing ſenſibly.

Laſtly to demonſtrate the excellency of this Doctrine, the example of the Tides in the Port of *Tunking* in *China*, which are ſo extraordinary and differing from all others wee have yet heard of, may ſuffice. In this Port there is but one Flood and Ebb in 24 hours; and twice in each Month, *viz.* when the Moon is near the Equinoctial, there is no Tide at all, but the Water is ſtagnant; but with the Moons declination there begins a Tide which is greateſt when ſhe is in the Tropical Signs: only with this difference, that when the Moon is to the Northward of the Æquinoctial, it flows when ſhe is above the Earth, and Ebbs when ſhe is under, ſo as to make high Water at Moons ſetting, and low Water at Moons riſing: But on the contrary the Moon being to the Southward makes high water at riſing and low water at ſetting, it Ebbing all the time ſhe is above the Horizon. As may be ſeen more at large in the *Philoſophical Tranſaction* Num. 162.

The Cauſe of this odd Appearance is propoſed by Mr. *Newton*, to be from the concurrence of two Tides; the one propagated in ſix hours out of the great *South-Sea*, along the Coaſt of *China*; the other out of the *Indian-Sea*, from between the Iſlands, in twelve hours, along the Coaſt of *Malacca* and *Cambodia*. The one of theſe Tides, being produced in North Latitude, is, as has been ſaid, greater, when the Moon being to the North of the Equator is above the Earth, and leſs when ſhe is under the

Earth; and contrarywiſe the other Tide that comes out of the *Indian-Sea*, being raiſed in South Latitude, is greater when the Moon declining to the *South* is above the Earth, and leſs when ſhe is under the Earth: ſo that of theſe Tides alternately greater and leſſer, there comes alwaies ſucceſſively two of the greater and two of the leſſer together every day; and the high-water falls alwais between the times of the arrival of the two greater Floods, and the low-water between the arrival of the two leſſer Floods. And the Moon coming to the Equinoctial, and the alternate Floods becoming equal, this Tide ceaſes and the Water ſtagnates: but when ſhe has paſſed to the other ſide of the Equator, thoſe Floods which in the former order were the leaſt, now becoming the greateſt, that that before was the time of high water now becomes the low-water, and the converſe. So that the whole appearence of theſe ſtrange Tides, is without any forcing naturally deduced from theſe principles, and is a great argument of the certainty of the whole *Theory*.

If by reaſon of the difficulty of the Matter, there be any thing herein not ſufficiently explained, or if there be any material thing obſervable in the Tides that I have omitted, wherein your Majeſty ſhall deſire to be ſatisfied, I doubt not but if your Majeſty ſhall pleaſe to ſuffer me to be admited to the honour of your *Royal Preſence*, I may be able to give ſuch an account thereof as may be to your Majeſties full content.

MVSEVM
BRITAN
NICVM